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Hypogenic caves in Provence (France): Specific features and sediments

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Abstract

Two dry caves from French Provence (Adaouste and Champignons caves) were until now considered as "normal" caves, evolved under meteoric water flow conditions. A new approach gives evidence of a hypogenic origin from deep water uprising under artesian conditions. Specific morphologies and sediments associated with this hydrology are discussed.

Keywords: hypogenic karst, hydrothermalism, subaqueous calcite deposits, condensation corrosion

1. Introduction

Most explored cave systems have evolved under seeping meteoric water carrying biogenic CO_2 under gravity flow, torrential type in the vadose zone or under hydraulic charge in the phreatic zone (Ford and William, 1988). Except for pseudokarsts resulting in processes other than solution, few minorities of cave systems find their origin in artesian and hydrothermal settings. Other factors of aggressiveness can be substituted to biogenic CO_2, like endogenous CO_2 linked to magmatic degassing, or H_2SO_4 stemming from sulphide oxidation of evaporites or hydrocarbon at depth. These are known as hypogenic caves. Hypogenic karst results from a source of aggressiveness produced at depth (CO_2 or H_2S) and is linked to confined or rising flow, without the direct influence of surface recharge. It corresponds approximately to artesian flow, where hydrothermalism is a variant (Klimchouk, 2000; Palmer, 2000). The sources of aggressiveness, although well localised, produce an enhanced solution resulting sometimes in enormous voids.

Corrosion and sedimentation gravific cave forms are in general well known from long term studies throughout the world (White, 2000). Hypogenic caves can go unnoticed if they are misleadingly attributed to a classic formation process, particularly in France where these phenomena are rare. The two examples shown here highlight sedimentation and corrosion forms, which do not result from gravific seeping (Forti, 1997; Dublyansky, 1997, 2000).

Adaouste and Champignons caves are located in Provence, in strongly folded Jurassic limestone (Fig. 1). The first opens at the top of Mirabeau cluse where the Durance River crosses it; the second is in the scarp of the famous Sainte-Victoire Mountain.

In the two caves, most of the morphological and sedimentary features related to classic gravific origin are totally absent:

- Rapid current flow features (scallops, potholes, vadose entrenchments...)
- Superficial or allogenic sediments dragged in depth by diffuse or concentrated recharge (clays from soil erosion, fluvial sands and pebbles, etc.)

In addition, general organisation of cave pattern, convergent to outflow point, does not match the common unconfined origin.

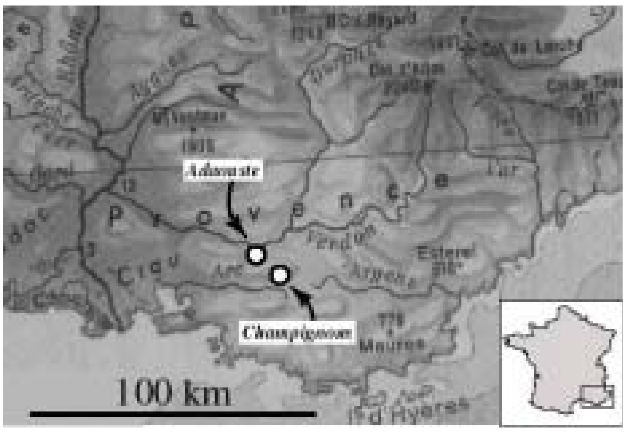

Fig. 1. Adaouste and Champignons cave locations

2. Champignons cave

2.1. Topographic and structural context

Champignons cave opens in the middle of the Sainte-Victoire mountain scarp, close to a gully, above Saint-Ser hermitage. The scarp corresponds to a truncated, thrusted anticline inverted limb (Corroy, 1957; Chorowicz and Ruiz, 1984). In this area the vertical dip at the cave base is found side by side with the sub-horizontal dip above.

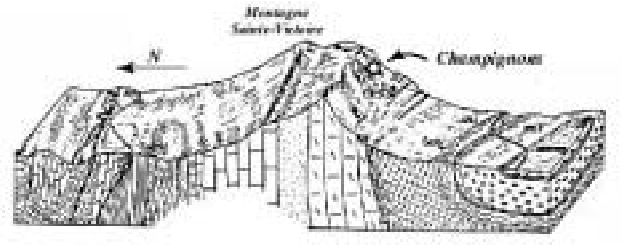

Fig. 2. Champignons cave, in the Sainte-Victoire Mountain overthrusting overturned fold (Corroy, 1957).

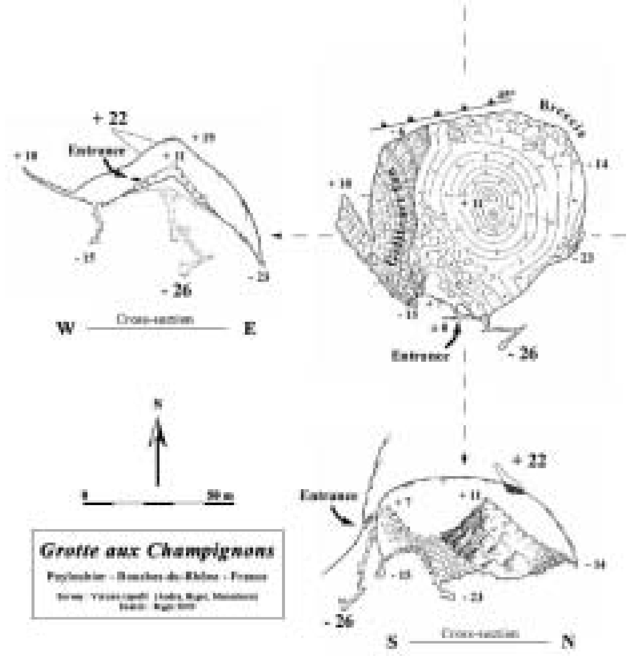

Fig. 3. Champignons cave survey.

2.2. Cave pattern organisation

A short tube-like pipe emerges in a vast, 60-m wide circular chamber, with a rounded roof. The ground is cluttered with big blocks, flowstone domes and a lateral alluvial cone comprised of gelifracts (Fig. 3). This feature comes from a torrential sinkhole next to a gully sink, which operated in a periglacial context. Except for these relatively recent gelifracts, the cavity and its sediments are relatively old. Moreover, there are three boundary rifts on the chamber side, going down about twenty meters between wall and blocks. They have a tendency to get smaller at the bottom.

2.3. Recharge upwelling from rifts. An intense but localised solution

The rifts that open along the chamber perimeter do not correspond under any circumstances to the runoff sink points that scoured the room. Their overhanging wall is notched by a few decimetre wide hemispherical channel aligned with the steepest slope (Fig. 14). Softly cemented angular blocks make up the chamber talus (filling like breccia) occupying the entire surface. Along the rifts, white limestone blocks, set in red cement, are rounded and corroded by small verticals tubes that sometime intersect breccia.

A generalised subaqueous calcite coating. Except for the localised corrosion zones, all of the rift walls are covered with an extremely pure 10-cm thick calcite crust. The crust is founded as a mammalies coating, a white microcrystalline popcorn, a nailhead spar or as dogteeth (Fig. 4). These deposits were formed in sluggish hydrodynamic conditions in water oversaturated with calcite (Dublyansky, 1997, 2000; Hill and Forti, 1997).

Solution induced by degassing of the uprising recharge. The following forms result unquestionably from the presence of ascending gas in a phreatic flow:

- Ceiling half-tubes have developed in the phreatic zone close to the water table as gas bubbles diffuse from the solution (like when opening a Champagne bottle), and run along the overhanging walls to reach the water table. The process of corrosion is induced by condensation which occurs continuously at the interface between the bubbles and the wall; these channels are referred as "bubble trails" (Chiesi and Forti, 1987).
- A generalised subaqueous spar coating formed from CO_2 diffusion from oversaturated water; these do not occur on overhangs along bubble trails where solution is predominant.

These rifts are thus produced by the juxtaposition of degassing solution phenomena and oversaturated water deposition. This simultaneity of solution / deposition phenomena in the same basin accounts for the proximity of both corrosion forms (bubble trails) and deposition forms (calcite coating). The transition is made over a distance of few centimetres at the edge of the channel. This combination constitutes an infallible identification criterion for identifying upwelling in a karst environment.

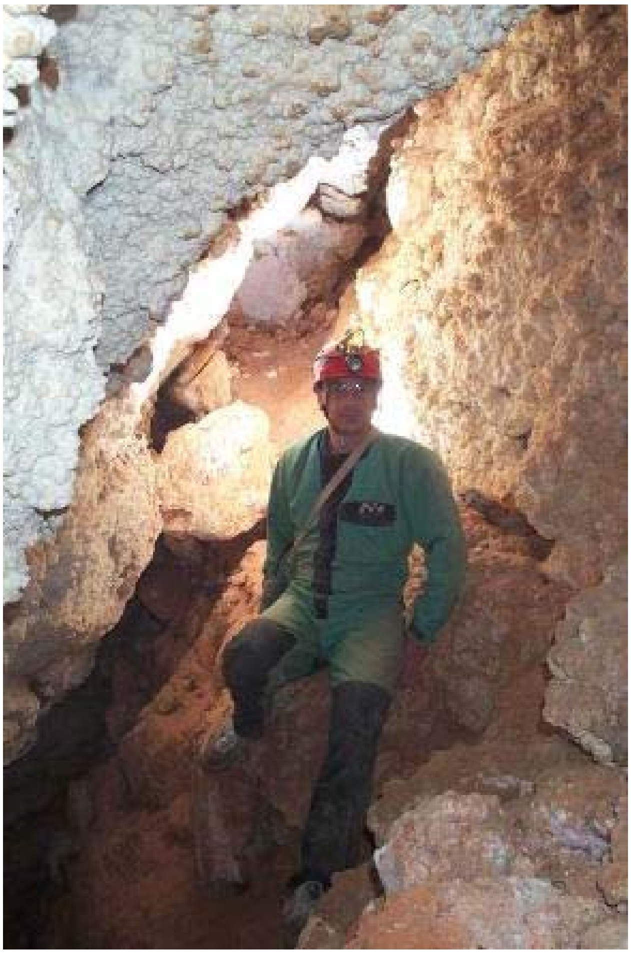

Fig. 4. Mammalies calcite coating on rifts walls.

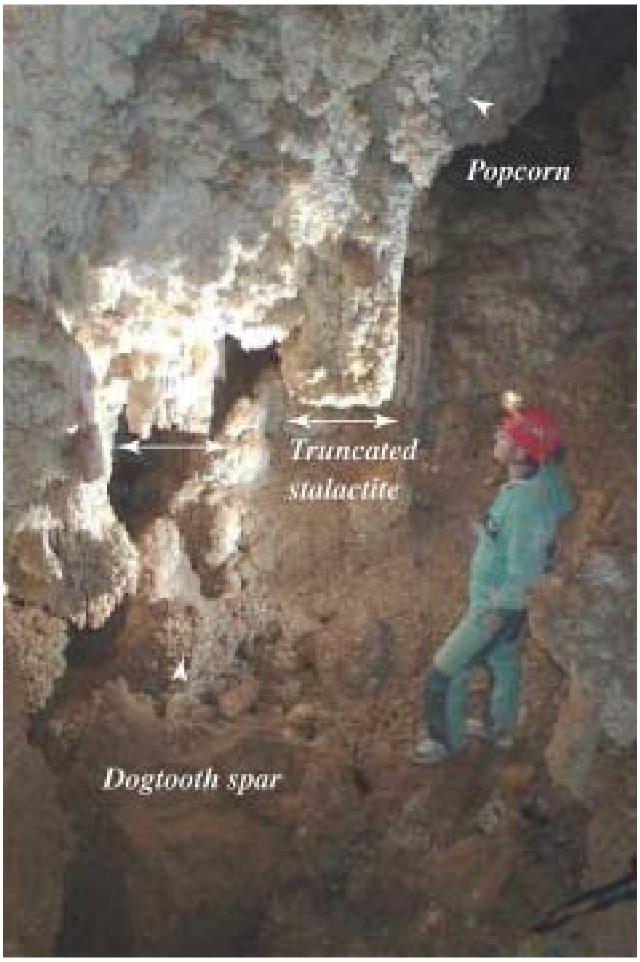

Fig. 5. Mammalies calcite coating and popcorns occurring on the lower part of the chamber, stalactites with basal truncation.

An attentive examination makes it possible to easily differentiate these key-forms from secondary corrosion phenomena of flowstones that are frequently observed and which are explained by chemical changes of seeping water, involving two successive and not simultaneous hydrochemical states.

2.4. Oversize room genesis

In comparison with the reduced size of the supply channels, the Champignons cave chamber appears oversized. Its study is not completed, but the following observations allow estimation of its origin:

- In the low part of the chamber a calcite coating occurs; it is of comparable nature to that of the cracks (Fig. 5), with stalagmites made up of dogteeth.
- Some massive stalactites do not have a sharp apex, but a horizontal truncation localised at various levels (Fig. 5). After examination, a break origin due to human activity is excluded.
- The upper part of the walls and the ceiling cupola present a naked and corroded rock with vast round forms and softened contours.
- The large central calcite dome (Fig. 2) presents both a rough surface and softened forms different from usual flowstones, and it overlies a scree accumulation made of angular blocks. Some stalagmites also have an unusual mushroom shape that accounts for the name of the cave.

The presence of subaqueous concretions (coatings and dogteeth) in the lower part of the chamber suggests that a lake once occupied it (Fig. 6). The existence of stalactites with horizontal truncation and the absence of quiet watermark indicate that the level of the water table must have varied. Degassing from deep water in the closed system has charged the atmosphere with carbon dioxide. The atmosphere in contact with the water table had to be relatively hot to cause condensation in contact with the colder walls. Combined with the CO_2 rich atmosphere, condensation was aggressive and corroded the emerged walls and ceiling. In the same

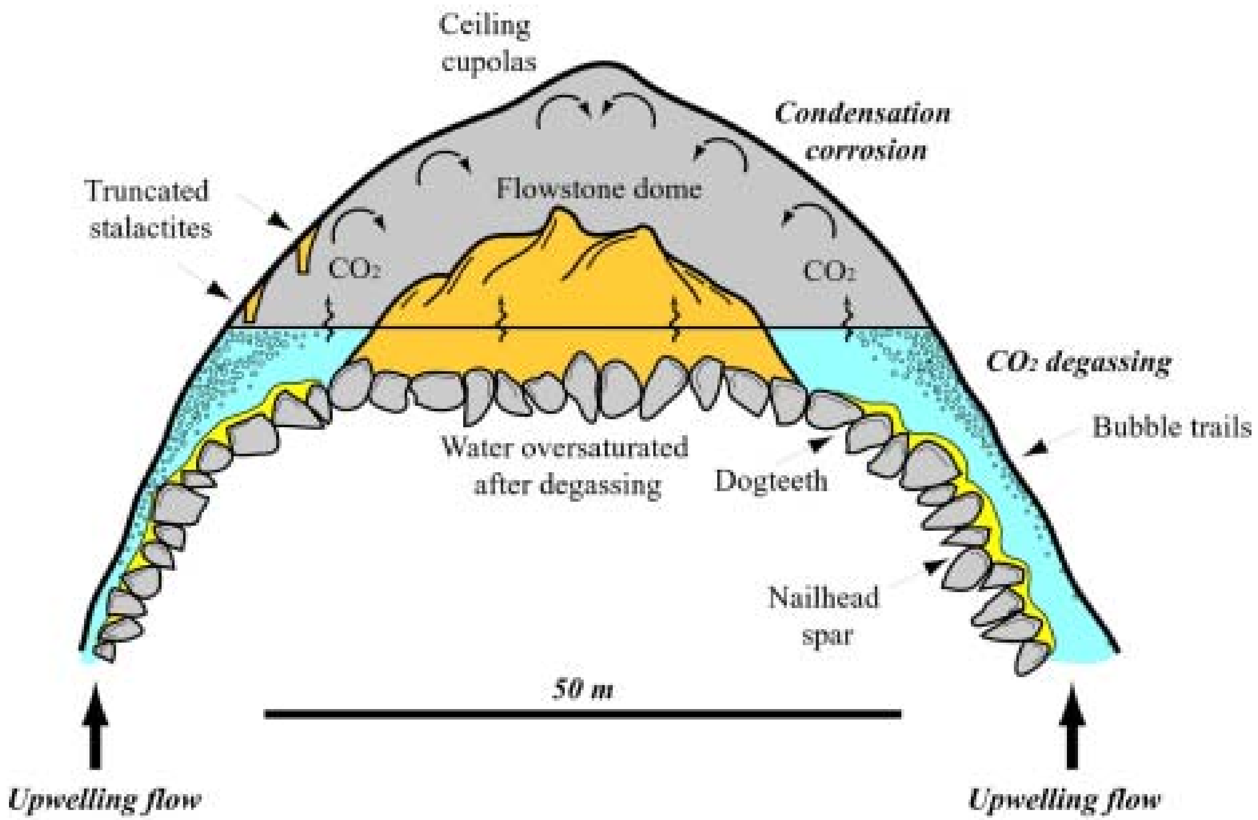

Fig. 6. Champignons cave hydrodynamic

way as in an aquatic environment, air convection currents must have occur, explaining regular cupola form of the ceiling in which more reduced size cupolas are fit.

As for the central dome and mushroom stalagmites, later research will probably show that they are subaqueous concretions of the same type as the Adaouste cave "Penitents" (*infra*). In any event, the hypothesis of flowstones corroded by a secondary flooding is incompatible with the presence of very angular underlying blocks, which would also have been corroded.

2.5. A probable age of Miocene or earlier

Arguments integrating this original cave in its external environment lack for the moment. The top Sainte-Victoire (969 m) is truncated by an infra-Oligocene planation surface, now uplifted (the Nicod's "fundamental surface", 1967). Tortonian sediments correspond to a marine shore at the occidental foot of the chain at the altitude of 400m. Without excluding tectonic movements, which could have exaggerated this altitudinal difference, it seems that Sainte-Victoire was individualised as an inselberg between these two chronological millstones. Champignons cave, located at middle height of the chain, marks undoubtedly an intermediate stationary period of base level during relief release. Although further study will allow testing of the hypotheses, an estimated age of 35 to 11 Ma between the two above-mentioned periods is assumed. It is interesting to note that the draining of the cave has enabled it to remain intact without any collapse since this period. The vault form ensures stability. No recent filling occurs except for the lateral intrusion of periglacial gelifracts and slight calcite deposition. The lack of surface recharge linked to seepage water is explained by missing connection with the overlying surface, which is closely related to its genesis *per ascensum*.

3. Adaouste cave

Adaouste cave opens at the top of the Mirabeau anticline limb entrenched by the Durance cluse (Fig. 7). It is a 3-D maze, organised in two downward series, strongly tilted (45-50°) with two horizontal levels occurring perpendicular to the anticline axis (Fig. 8). In the absence of impervious strata, these two levels record old base level positions, which correspond to the Mirabeau cluse entrenchment.

Fig. 7. Adaouste cave location, at the top of the Mirabeau anticline with truncated saddle, entrenched by the Durance cluse (Photo. J.-L. Guendon).

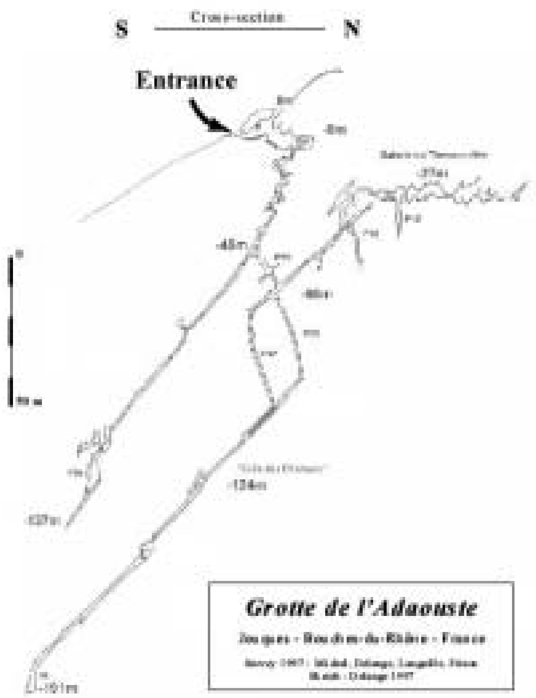

Fig. 8. Adaouste cave survey.

3.1. Corrosion-deposition in deep series

In Adaouste, we find the same phenomena as in the Champignons cave, upwelling of aggressive deep water and simultaneous calcite deposition by carbon dioxide degassing. “Penitents” chamber at -124 m harbours the most interesting phenomena. It is unknown if this phenomenon occurred at depth in a ceiling pocket with trapped gas or near the water table when base level was at this altitude.

Deep origin water is decompressed during uprising and releases dissolved carbon dioxide. Bubbles accumulate in a ceiling pocket, probably exclusively filled with this gas. Water condenses in contact with the relatively fresher roof. It is extremely aggressive due to the strong CO_2 partial pressure. Condensation corrodes the ceiling and forms a boxwork (Fig. 9) (Palmer and Palmer, 2000).

Degassed water becomes oversaturated and deposits calcite on the walls. Several types of subaqueous calcite deposits were identified:

- Folia, along the overhanging ceilings (Fig. 10). These deposits look like inverted rimstones. Their origin, the detail of which is still not entirely known, involves simultaneous deposition on the lower edge and corrosion in the pocket where the carbon dioxide is trapped in sluggish hydrodynamic condition (Hill and Forti, 1997).

- On the ground small tower coral grow up to 10 cm high. These deposits, which correspond to a calm supersaturated environment (Hill and Forti, 1997), should not be confused with encrusted silt pillars, like the “100 000 Soldiers” of Trabuc cave (Gard, France) which result from completely different processes.

- “Penitents” found on the basin surface. Their form evokes normal stalagmites but they correspond to tower cones (Fig. 11). On the surface of the supersaturated basin, cave rafts form. Condensation droplets flow along the ceiling and drip at the same place from sharp ends. Dripping water sunk rafts at discrete points. With time, they accumulate and are cemented, building a tower cone (Forti and Utili, 1984).

- The preceding types were located in sluggish hydrodynamic conditions, away from the main drain where the current went up. In slightly more agitated zones calcite coatings dominate with vuggy structure, dependent on fast crystal growth in a strong degassing context (Forti, person. comm.). Two principal types are identified: a) Saccharoid texture white calcite flakes accumulation, with many interstitial vugs (Fig. 12), and b) Popcorns, reaching sometimes significant dimensions (20 cm and more). Directional coralloids clearly show an ascending current. In section, three kinds of fabric appear: white calcite at the origin, whose structure is covered by red cement and then by a laminated greyish growth in periphery (Fig. 13).

3.2. Horizontal galleries at the water table

Below water table, carbon dioxide degassing produces various types of forms according to the local structural context:

- In oblique bedding planes, bubble trails similar to those described in Champignons cave, corrosion at the ceiling and calcite deposition at the bottom forming popcorn (Fig. 14).

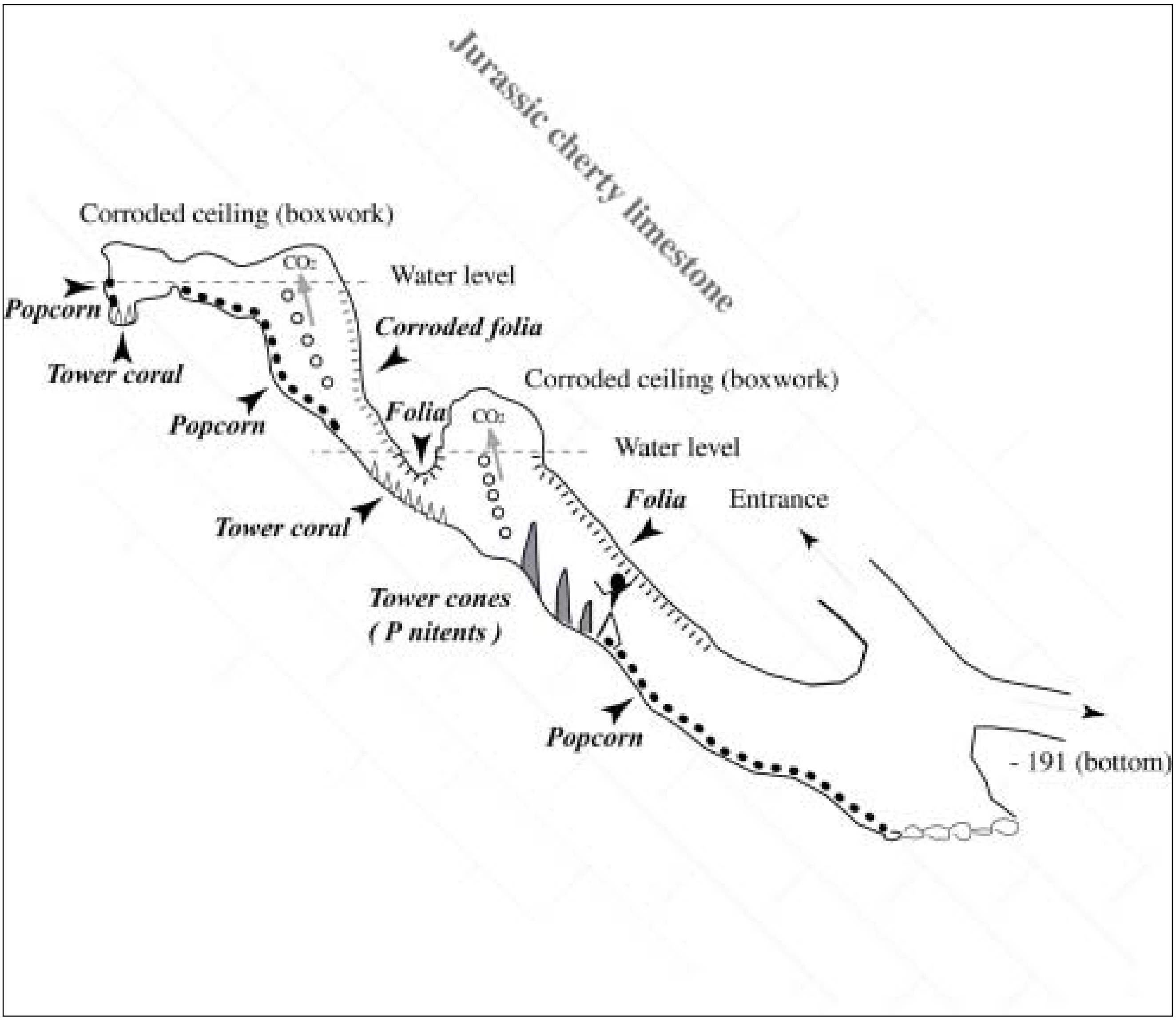

Fig. 9. Condensation corrosion in the ceiling pockets and subaqueous calcite deposition

Fig. 10. Subaqueous calcite; folia on the overhanging walls and tower coral on the ground

Fig. 11. Penitents chamber cone towers, subaqueous stalagmites made of calcite rafts accumulation

Fig. 12. Subaqueous saccharoid calcite coating.

Fig. 13. Subaqueous large size coralloids.

- In the tilted rooms developed under a layered roof, ascending bubbles follow the contact with the ceiling, forming braided channels by corrosion and isolating pendants similar to elephant feet (Fig. 15).
- Vertical rifts allow a fast water rise ("P12" and "P13" in Fig. 8). They are present in the form of elongated fissures, which enlarge when approaching the gallery edge.

Fig. 14. Tubular bubble trail, corroded by ascending gases, with ceiling channel and popcorn on the bottom.

Fig. 15. "Elephant feet" like pendants derived from braided bubble trails originating from aggressive ascending bubbles.

When approaching the water table, ascending water mixes with meteoric seepage, enhancing mixing corrosion and giving rise to conduit development. Slow water flow towards a close outlet generates a horizontal current. Rectilinear tube-like galleries develop (figure 16), cutting structural discontinuities which are vertical rifts or tilted bedding planes that provide only local enlargements.

Fig. 16. Horizontal tube-like gallery in the upper series, with intensively corroded massive flowstones.

Except for some recent "normal" flowstones linked to the presence of the nearby surface, the most important parts of the chemical and clastic deposits are related to the original upwelling dynamic of the cave.

- Massive flowstones (stalagmites, stalactites, columns…) have been intensively corroded by flows (Fig. 16). Some ceiling cupolas equally cut the host rock and the flowstones. The presence of such formations implies a genesis in several steps: (i) conduit initiation, (ii) lowering of the water table allowing calcite deposition, (iii) corrosion of the flowstones during flooding.

- Clay sediments of superficial origin were deposited in horizontal sequences by the phreatic flows. They are localised only in some nooks. The study of these deposits remains to be done. In general, river sediments are rare and the cave is clean. There are some red clays which came from the surface after the draining of the system in a recent phase.

- In the entrance series pockets filled of light yellow sands and cut by the ceiling cupolas occur, like well calibrated gravel containing tortonian marine fauna (Conrad and Onoratini, 1997). These deposits are related to the leaching of the tortonian clastic formations, which cover the plateau’s surface (marine sediments and “Bèdes gravel”).

3.3. A tortonian hypogenic cave system

The knowledge of the local paleogeographic evolution allows an accurate identification of the age and evolving conditions of the cave (Clauzon, 1979, 1988; Delange, 1997; Nicod, 1967; Rousset, 1963).

- **Middle Miocene. T**he anticline is truncated by a wave cut platform (present altitude of 430 m). Karst could have occurred after this stage but without any relation to the Adaouste system.

- **Tortonian.** A transgression / regression cycle allows marine and then river deposits (“Bèdes gravel”) which spread on the surface.

- **Upper Tortonian (8.5 to 5.8 Ma; Fig. 17-1).** The fluvial network entrenches in the sediments and then cuts by superimposition the anticline vault. An artesian aquifer in limestone outflows across this window. The two horizontal series of the entrance area mark two successive steps of the Durance entrenchment, corresponding to a valley embankment of 40 m under the plateau’s surface. Afterwards the tectonic movements warp the anticline, which is raised up from about 100 m. The Durance adapts by an antecedence phenomenon and the upper part of the cave drains.

- **Messinian (5.8 to 5.3 Ma; Fig. 17-2). T**he salinity crisis of the Mediterranean Sea shows up by a powerful embankment of the tributary valleys. The Durance thalweg lowers by more than 200 m into the Mirabeau anticline (present elevation of 87m asl.). The Adaouste is totally drained, the ascending water having to find an outlet in the bottom of the messinian canyon.

- **Pliocene (5.3 to 2.5 Ma; Fig. 17-3). T**he “high stand” marine transgression floods the canyon in a ria and fills it with marine sediments. River aggradation lifts the base level up to 40 m below the entrance (altitude of 370 m). The cave is flooded, but it is presently unknown if hypogenic recharge still occurred.

- **Upper Pliocene and Quaternary (from 2.5 Ma).** Due to eustatic (lowering of the sea level) and tectonic (plio-quaternary uplifting) causes, the Durance entrenches down by successive stages and removes 150 m of the Pliocene deposits down to the present altitude of the valley (220 m). The clay deposit in the Adaouste’s bottom is at the same altitude. The intrusion of men and bats leaves archaeological traces and phosphatic minerals, respectively, in the recent entrance sediments (Conrad and Onoratine, 1997).

In brief, the hypogenic activity of the cave is related to the Upper Tortonian. Then the cave was drained, flooded and finally definitively dried. Last events did not leave tangible marks. It seems that the cavity has not evolve significantly since messinian drainage.

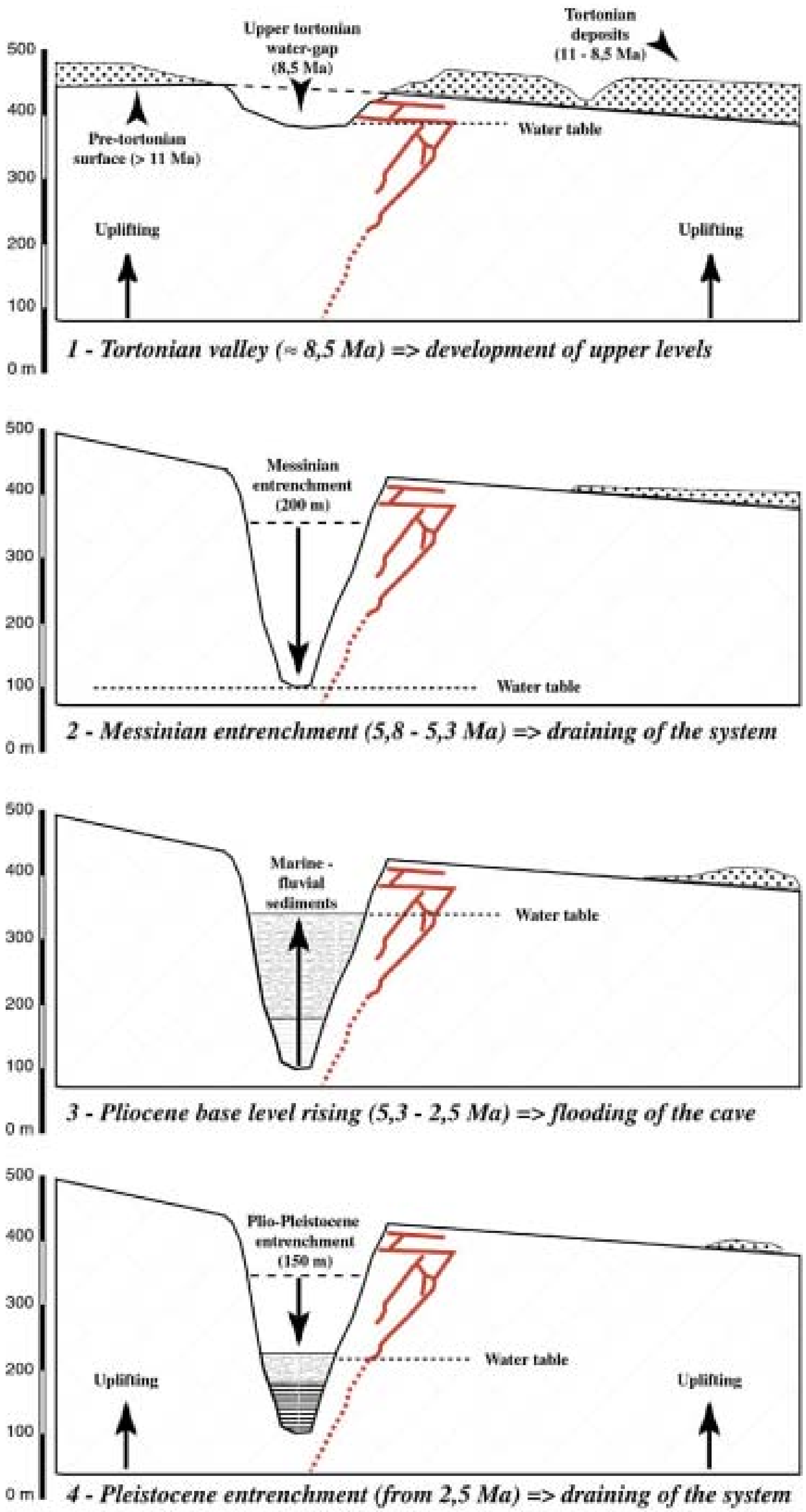

Fig. 17. Adaouste cave evolution since Miocene (after Delange, 1997)

4. Conclusion

This preliminary study permitted the identification of a hypogenic origin for the two cave systems for which the activity age was approximately the Miocene. The findings suggest new research routes:

- In the paleogeographic field, a better knowledge of the regional geomorphologic evolution would better define the chronology and evolution framework of the systems.
- A structural study would establish the origin and cause of the artesian flow.

The object of this preliminary study was the definition of morphological and sedimentary indicators for hypogenic karst. Many specific corrosion forms and calcite deposits had been clearly identified.

The study indicates that water went up from great depths, sufficiently rapidly to have thermal characteristics. Recent measurements of fluid inclusion microthermometry confirm this, suggesting calcite deposition conditions in a range of 85° C to 230° C. Geochemical isotopic analysis has to be done to determine the water composition which should enriched in carbon dioxide.

The hypogenic origin of these caves requires that the development of certain cave systems and karst stages in Provence be partly reconsidered.

Acknowledgements

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